# Modeling and Simulation, Experimentation, and Wargaming - Assessing a Common Landscape

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**The efficient and effective exploration of "what if" questions is fundamentally necessary to ensure the continued preeminence of U.S. military forces. Accomplishing this mission requires human ingenuity, insight and creativity, as well as the rigorous application of formal analytical methods. Principal among these methods are: *modeling and simulation*, *experimentation* and *wargaming*. In this white paper, we briefly review the current state of each, noting their fundamental interrelationships, and identify opportunities for future focus and community investment. Our assessment also includes a discussion of MITRE capabilities across these three disciplines.**

## 1 Modeling and Simulation

Modeling and simulation (M&S) pervades science and engineering in all its applications. It has been suggested that [1]:

> Today we are at a *tipping point* in computer simulation for engineering and science. Computer simulation is more pervasive today – and having more impact – than at any other time in human history. No field of science or engineering exists that has not been advanced by, and in some cases transformed by, computer simulation. Simulation has today reached a level of predictive capability that it now firmly complements the traditional pillars of theory and experimentation/observation. Many critical technologies are on the horizon that cannot be understood, developed, or utilized without simulation.

Some estimates establish total U.S. expenditures on M&S at $50B USD annually, including $9B USD within the Department of Defense (DoD) [2].

M&S supports the full range of defense missions – from concept exploration, analysis, acquisition, test and evaluation, planning, development of doctrine and tactics, operations, and training – within each Service and within the Joint commands.

Over the past several decades, the defense community has made great strides in establishing the community of interest and practice surrounding M&S: OSD, Joint and Service offices were established for management and coordination of M&S-related activities; policies and standards have been developed and promulgated; federations of interoperating defense simulations have become commonplace; knowledge management repositories created; and research funding shaped through community-wide engagement.

There have also been missteps. The revolution in defense business practices to be brought about by Simulation-Based Acquisition (SBA) [3] and the Army's Simulation and Modeling for Acquisition Requirements and Training (SMART) initiative [4] were

never fully-realized. The failure of the Army's Future Combat System (FCS) – prominently touted as an example SBA/SMART acquisition program [5] – caused some in leadership to question the value of M&S all together. Support and funding for the OSD-level management activities conducted by the Defense Modeling and Simulation Office (DMSO) (established in 1991, and redesignated the Modeling and Simulation Coordination Office (MSCO) in 2006) has waned over the last decade.

Looking forward, some of the challenges facing the defense M&S community include:

- *Demonstrating the Return on Investment (ROI) of M&S.* Practitioners and advocates for the technique recognize the need to definitively illustrate its value to policy and decision makers. Historical efforts by the General Accounting Office (GAO) and others to quantify the cost-effectiveness of M&S investments have yielded mixed results [6, 7]. Recent efforts have shown notable progress in defining metrics to support ROI calculations [8].

- *Representation of new systems, technologies and challenges.* In particular, the representation of cyber and cyber effects, space systems, and Anti-Access Area-Denial (A2AD) environments.

- *Representation of threat systems.* A perpetual challenge in defense M&S involves updating our threat models in accordance with our best-available intelligence data. The recently developed ITASE framework may provide a useful long-term solution for many defense M&S applications.

- *Live-Virtual-Constructive integration.* The integration of Live, Virtual and Constructive (LVC) simulation elements portends an opportunity to maximize the effectiveness of training, experimentation and mission rehearsal environments. However, improper or inadequate integration of these elements can have deleterious effects. As Maj. Gen. James Jones, Air Force Assistant Deputy Chief of Staff for Operations, Plans and Requirements, said in a December 2013 keynote at the Interservice/Industry Training, Simulation and Education Conference (I/ITSEC), "I don't think any of us here today would say that we're where we need to be. In order for us to truly achieve an impact on readiness, we must take the next steps toward a complete integration of live, virtual and constructive assets."

- *Low-overhead event support.* In addition to the overhead associated with role players, most training and experimentation events have considerable overhead in technical support personnel. The provision for such technical support is a major impediment to the DoD's ability to fully realize its vision for Home Station Training.

## 2 Experimentation

Experimentation is intrinsic to the scientific method – providing any reasonable history of its application in a defense context is beyond the scope of this white paper. In the modern era, most of the concepts, methods and activities associated with defense experimentation are aligned with the *Code of Best Practices for Experimentation,* which grew out of the Command and Control Research Program (CCRP) and its focus on network-centric warfare and military transformation [9]. The code identifies three categories of experimentation, as applied within the DoD:

- *Discovery experiments* involve introducing novel systems, concepts, organizational structures, technologies, or other elements to a setting where their use can be observed and catalogued.

- *Hypothesis testing experiments* are the classic type used by scholars to advance knowledge by seeking to falsify specific hypotheses (specifically ifthen statements) or discover their limiting conditions.

- *Demonstration experiments* in which known truth is recreated, are analogous to the experiments conducted in a high school, where students follow instructions that help them prove to themselves that the laws of chemistry and physics operate as the underlying theories predict.

In addition to differentiating experiments by their purpose, we can also differentiate experiments by scale and complexity. Such a spectrum of experimentation might include:

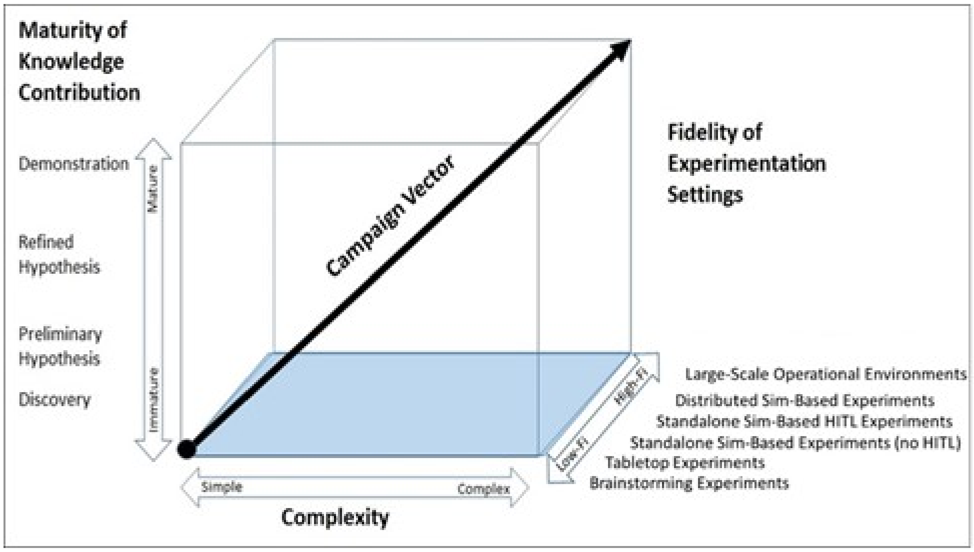


**Figure 1:** *The Experimentation Campaign Space (adapted from [9]).*

- *Brainstorming events* - gain knowledge on a specific topic through a specialized environment for innovative thinking.
- *Tabletop events* - assess a topic one situation at a time.
- *Scenario-Based Demonstration and Prototyping* - experiment with a concept using a prototype.
- *Standalone Simulation-Based Experiments, without runtime human interaction* - experiment with a concept using a simulation that runs uninterrupted.
- *Standalone Simulation-Based Experiments, with Human-in-the-Loop* - experiment with a concept using a single interactive simulation.
- *Distributed Simulation-Based Experiments* - experiment with a concept using an integrated set of interactive simulations and C4I systems.
- *Large-Scale Experimentation in Operational Environments* - experiment with a concept using a large-scale integrated set of interactive simulations and C4I systems in an operational environment.

We see from the list above that experimentation is not completely disjoint from M&S. In many cases, simulations provide a basis for an experimental environment. Similarly, many of these classes of experiments may also be viewed as wargames.

In a follow-on to the *Code of Best Practices*, Alberts and Hayes emphasize that experiments should be regarded as part of an ongoing process, rather than as "one off" events [10]. As illustrated in Figure 1, above, a *campaign of experiments* should involve experiments from different parts of the experimentation fidelity spectrum – a concept that seems promising based on a tabletop experiment may be explored in more detail using a simulation-based experiment, or a concept that fares well in a standalone simulation may be further assessed in a more complex distributed simulation experiment.

While Programs of Record may conduct experimentation as part of system design and development, the preponderance of experimentation-related activity across DoD is in support of pre-acquisition concept development.

Recently, the Defense Science Board (DSB) has called for [11]: "an increased use of experimentation for discovery and analysis of potential new technologies. This would replace the current Department focus on test and evaluation and developmental milestones."

The Air Force has responded to this challenge by funding both a MITRE study and Air Force Studies Board examination on AF experimentation policies and practices, and the creation of a Strategic Development Planning and Experimentation (SDPE) Office

within the Air Force Materiel Command (AFMC). The Air Force has earmarked $87M for experimentation in the FY17 President's budget.

Current challenges facing defense experimentation include those cited previously for M&S. In addition, the experimentation community could benefit from the governance structures, knowledge management processes and properly designated and resourced "vision" centers, like those that have been established within the M&S community. The Air Force SDPE Office is a positive step in that direction. The other Services and Joint community should consider a similar approach.

## 3 Wargaming

At its core, wargaming is a tool for exploring human decision-making, particularly in environments with incomplete and imperfect information. Perla defines wargaming as [12]: "...a warfare model or simulation whose operation does not involve the activities of actual military forces, and whose sequence of events affects and is, in turn, affected by the decisions made by players representing the opposing sides."

Typically, wargames are strategically focused. During the course of a wargame, players may discover the need to make unanticipated decisions in order for the game to progress. According to [13] , there can also be an educational component to a wargame. Experience has shown that players learn from each other while participating in the wargame. Most players find the exchanges of ideas and information that occur during a wargame to be professionally rewarding.

Some common types of wargames are [14]:

- *Table-Top Exercise.* A table-top exercise is a discussion-based wargame where players sit at tables and interact with one another to address the key issues of the wargame. While not specifically structured as a turn based game, facilitators will often cause players to consider issues in a particular order, to determine the relationship between specific decisions or actions.

- *Workshop.* Workshops involve subject matter experts (SMEs) gathered to discuss a problem. Workshops have a narrow, discrete focus, and often serve as an input to follow-on events.

- *Inductive game.* Inductive games begin without a pregame concept. With inductive games, the concept is discerned after analyzing game data for patterns. This type of gaming is used early in the concept development process, and makes use of open-ended brainstorming styles during the event.

- *Deductive game.* In contrast, deductive games begin with general game ideas to be tested, followed by observations collected during the game to support or refute the initial game hypothesis. This type of gaming is used later in the concept development process, after the concept is more fully developed. This is used during course of action (COA) analysis or to test a plan prior to execution.

- *Scenario-based game.* This technique presents players with a specific scenario, which is used to guide the course of the wargame while the players examine a particular strategic problem or issue. Scenario based games, starting with present-day conditions, can be used to "take an intellectual walk into the future." Based on a sponsor's requirements, the wargame may be based on a specified scenario.

- *Alternative futures game.* An alternative futures wargame involves presenting the participants with two or more scenarios of a plausible future. Players are asked to determine key indicators that would signal that the future represented by the scenario might be emerging. In contrast to the scenario based game, an alternative future game starts in the future and works backward to the present. Game results often include identifying both unique and common indicators from across several scenarios. Toward the end of game play, the players may be asked to identify what they believe is the most plausible future based on game play.

- *Single-sided game.* A single- or one-sided game includes one player cell, with the opposition furnished by a control group that presents scripted scenario injects.

- *1 1/2-sided game.* A 1 1/2-sided game also includes one player cell, with the opposition furnished by a control group, but with scenario injects developed

during game execution, versus pre-scripted, to force the players to wrestle with specific decisions related to game objectives.

- *Two-sided game.* As contrasted with a 1-sided game, two-sided games involve two separate, competing player cells. The two sides play by rules that vary from restrictive to entirely free play. Player decisions from each cell are adjudicated, with results presented to the players and used to inform subsequent game play.
- *Multisided game.* Games may be designed with several competing cells. These games are referred to as multisided, or by the actual number of sides (e.g., "three-sided"). The rules of conduct for multi-sided games can be significantly more complex than in a two-sided game due to the number of possible interactions between the various player cells.

Wargaming has a rich history in the U.S. military. The Naval aviation community's deliberate and aggressive use of wargames during the 1930s is often credited with the defeat of the Japanese carrier force at the Battle of Midway in the Second World War [15]. Today, the military wargaming community remains active. However, a recent review of Service and Joint wargaming revealed a lack of coordination within the wargaming community and the absence of any direct link between the insights gained from wargaming and the Department's programmatic action. As a result, the DoD leadership has called for focused efforts to reinvigorate wargaming across the Department [16].

As part of this reinvigoration process, DoD has created a classified wargaming repository, and established a Defense Wargaming Alignment Group (DWAG). The DWAG will undertake an inventory of wargaming capacity and capability across DoD, particularly among the Services and the Combatant Commands. It will also institute a series of regularly occurring senior leader wargaming events.

DoD leadership is also asking the War Colleges and Schools to consider making wargaming courses more intrinsic to their curricula. In many cases today, wargaming courses are electives. The Pentagon has requested \$55M for wargaming in FY17 and more than \$525M over the five-year Future Years Defense Program spending plan [17]. The wargaming program will focus on three time horizons:

- Near-term (present - 5 years): operations and logistics
- Mid-term (5-15 years): new capabilities and operational concepts for issues, such as overcoming A2AD strategies
- Long-term (beyond 15 years): technology trends and future challenges

# 4 M&S, Experimentation and Wargaming at MITRE

We note the significant overlap in the underlying technologies, techniques and methods associated with M&S, experimentation and wargaming. At MITRE, we see some synergy of language and methodology across the researchers and practitioners of these disciplines, but there remain disconnections that can and should be resolved. We review the MITRE landscape in these disciplines below. The discussion is not a comprehensive survey of MITRE's capabilities or its past or current work program in M&S, experimentation and wargaming. Our objective is simply to illustrate the breadth of work ongoing, point out areas of commonality, and highlight a few notable efforts and directions of future focus.

## 4.1 MITRE capabilities today

Looking first at M&S, we observe that it is arguably a *fundamental* technology, intrinsic to many of MITRE's sponsor's missions. M&S technologies are being developed and applied extensively throughout MITRE across the range of its sponsor base in the Department of Defense, Intelligence Communities, and Civil Agencies, and their many missions - systems design and analysis, experimentation, wargaming, training, mission rehearsal, and test and evaluation. A few notable application areas, include:

- *Communications and Networking* MITRE sponsors' missions include military operations, humanitarian operations, Intelligence Community operations, civil aviation operations, and first responder operations. These missions entail a growing dependence on communications and networking and an increasing need for resilience. MITRE maintains significant expertise in design, analysis, and implementation of networks

across a diverse set of communication environments including virtual, wired, tactical wireless (MANET), optical, cellular, commercial wireless (LTE, WiFi, and WiMAX), and SATCOM. Some areas where M&S has played a critical role include: disruption tolerance [18], encryption [19], and spectrum management [20].

- *Command and Control.* Since its founding in July 1958, MITRE has been a prominent contributor to the advancement in both Federal Aviation and DoD Command and Control (C2) architectures and systems [21]. MITRE has supported the design and development of many of the fielded C2 systems and their supporting protocols, as well as in the evolution of C2 concepts of operations, and linkages between M&S and C2.

- *Intelligence, Surveillance and Reconnaissance* . MITRE conducts a wide variety of ISR modeling and analysis activities from very high-fidelity phenomenological models for bistatics radar, Position Navigation and Timing (PNT) technologies, etc., to aggregated analysis of mission and campaign-level ISR effects.

- *Aviation.* MITRE works with the Federal Aviation Administration to provide the safest, most efficient aerospace system in the world and to meet the evolving needs of the nation's airspace. M&S contributions to this domain include: analysis of system-wide en route [22] and terminal area [23] traffic flows, evaluation of aviation safety operations [24], and Human-in-the-Loop experimentation and training for air traffic control operations [25].

- *Systems Engineering of Simulation-Based Systems.* MITRE has been playing a leading role in the development of distributed simulation technology for nearly 30 years. Dating to its leadership in the DARPA Synthetic Theater of War (STOW) [26], and the subsequent community-wide effort to develop scalable and reliable technologies for simulation interoperability, MITRE played a key role in the establishment of the Defense Modeling and Simulation Office (DMSO), and subsequently "wrote the book" on the High Level Architecture (HLA) [27]. MITRE remains on the forefront of the evolution, standardization and application of advanced distributed simulation architectures, and simulation-C4I interoperability through systems engineering roles on many of today's most critical individual, collective and command-post training and experimentation systems [28, 29], and leadership with a variety of initiatives to further the application of Live Virtual Constructive (LVC) architectures.

- *Applications of Institutionally-Adopted M&S Systems.* MITRE engineers and scientists have expertise in the application of many of the standard modeling platforms used by the U.S. Government, including: JANUS, JCATS, JTLS, EADSIM, Eagle, Combat XXI, STORM, JSAF, SEAS, OneSAF.

- *Large-Scale and High-Performance M&S.* MITRE researchers have been developing new approaches for High Performance applications of M&S for several decades. Notable examples of this work include: conservative protocols for parallel discrete event simulation [30], optimistic parallel discrete simulation of air traffic [31], simulation and parallelized linear inequalities [32], and multi-paradigm simulation of large-scale wireless networks [33].

- *Model-Based Systems Engineering.* MITRE has played an active role in the development and promulgation of standards for MBSE.

- *Complex Systems Modeling and Analysis.* Claiming numerous graduates of the Santa Fe Institute for Complex Systems, MITRE has applied complex systems modeling and analysis in wide range of domains, including: asymmetric warfare [34], disease spread [32], critical infrastructures [35], and financial markets [36].

- *Autonomy.* M&S plays a central role in MITRE's research and practice in the area of autonomy [37]. For example, the simulation of the sensing and control systems for MITRE's Meteor entry into the 2005 DARPA Grand Challenge evolved directly into the actual system software [38]. M&S is also fundamental to the design of millimeter-scale robots [39], and Unmanned Aerial Vehicles (UAVs) [40].

| Experimentation Level | Purpose | Example |
|---|---|---|
| Engagement Planning and Problem Definition | Helps a diverse group of stakeholders identify and achieve consensus on the key questions for experimentation. | Collaborative Adaptable Framework for Engineering(CAFÉ) |
| Brainstorming Events | Places participants in a collaborative environment designed for innovative thinking to produce concepts for further exploration. | Agile Capability Mashup Environment (ACME) |
| Tabletop Experiments | Assesses the pros and cons of different courses of action for a collection of static situations. | Information Sharing Experimentation Environment (ISEE) |
| Scenario-Based Demonstration and Prototyping | Explore issues related to new systems using dynamic scenarios to evaluate prototypes. | MITRE Aviation Safety Discovery Laboratory |
| Standalone Simulation-Based Experiments | Determines the impact of a new technology or procedure on measures of effectiveness through multiple simulation runs. | Reusable Analytic Decision Experiment (RADE) |
| Distributed Simulation-Based Experiments | Investigate the interoperability of new technologies or tactics, techniques, and procedures with a system of systems. | National Security Experimentation Laboratory (NSEL) Simulation Experiment (SIMEX) |
| Large-Scale Experimentation in Operational Environments | Evaluate new technologies and war fighting concepts in a simulated wartime battle environment. | Office of Naval Research (ONR) Limited Technology Experiment (LTE) |

**Figure 2:** *MITRE Activities Across the Experimentation Spectrum.*

- *Cyber.* Advanced cyber adversaries have growing arsenals that include attacks on the global supply chain, insider subversion, physical attacks on supporting infrastructures, electronic-warfare attacks, social engineering, and slow-moving cyber attacks. These are increasingly being blended and orchestrated to achieve effects on a wide range of targets, including enterprise networks, tactical networks, embedded systems, cyber physical systems, etc. Adversaries have established a persistent, embedded presence on some of our networks, and their advanced blended-attack campaigns are very hard to prevent or even detect. M&S challenges in the cyber arena are many, particularly in the area of assessing the mission impacts of cyber effects [41].

- *Optimization and Metamodeling.* MITRE researchers have developed numerous enabling technologies to support very large-scale and realtime decision support frameworks, including simulation-based optimization [42], metamodeling [43], and grid-computing frameworks [44].

In addition to its significant base of M&S activity, MITRE has over 20 distinct labs and facilities supporting a wide range of activities across the experimentation spectrum. A few of these are noted in Figure 2.

One of MITRE's more prominent experimentation activities is its **National Security Experimentation Lab** (NSEL). NSEL responds to the need for operationally realistic environments where MITRE sponsors can conduct detailed investigations into new and innovative concepts, technologies, platforms, systems, and tactics, techniques, and procedures (TTPs). The NSEL provides affordable, dynamic experimentation designed to bring new capabilities one step closer to the operational community. It enables MITRE and our partners to conduct simulation experiments, or SIMEXs, with real Command and Control (C2) systems, simulated weapons and sensors, and real military and civilian operators executing various crisis action scenarios. Conducted in distributed environ-

ments over NIPRNET, SIPRNET, DREN, SDREN, and Virtual Private Networks (VPNs), these SIMEXs address interoperability among systems and evolve concepts of operation and TTPs using advanced technology.

MITRE has evolved NSEL from testing time-sensitive targeting initiatives to addressing other mission areas and scenarios associated with military operations and homeland security. NSEL conducts four to six SIMEXs per year and has served as home base for 46 events since 2002. Each SIMEX lasts one week, but the preparation process usually takes several weeks to months.

Other notable experimentation activities at MITRE are supported through the **Resources for Early and Agile Capability Testing** (REACT) lab, the **Agile Capability Mashup Environment** (ACME), and the **Integration Demonstration and Experimentation for Aeronautics** (IDEA) lab.

MITRE's connections with the wargaming community are arguably less prominent than those with the defense M&S and experimentation communities. MITRE's **National Security Analysis Group** (NSAG), however, has supported a variety of wargaming efforts, including the series of "Space Games" conducted by OUSD(P) under then-USAF Maj. Gen. Santee, and a recent ISR wargame under the sponsorship of OUSD(I).

### 4.2 MITRE investments in future capabilities

Strategic planning within MITRE and its operating centers is an ongoing process, and outside the scope of this white paper. We note, however, the emerging and growing interest in strategic analysis, multi-domain command and control (C2), command center operations, resilience, autonomy, and cyber, to name a few. The opportunities and challenges for modeling and simulation, experimentation and wargaming in these problem domains are numerous; we will examine specific opportunities in other white papers. For purposes of this article, we note a few ongoing initiatives that should support M&S, experimentation and wargaming across the range of emerging topics of interest:

- Opening in January 2017, MITRE's Simulation Experimentation and Analytics Lab (SEAL) will provide a state-of-the-art facility to support command and operations center experimentation, immersive visualization, and interactive strategic analysis.

- Within MITRE's Independent Research and Development (IR&D) program, its "Future of C2" innovation area is expected to employ M&S, experimentation and wargaming to explore future concepts and methods for C2, particularly in support of multi-domain operations, and disconnected, intermittent and low-bandwidth environments.

- The Networked Experimentation, Research, and Virtualization Environment (NERVE) is being developed to provided interconnectivity among MITRE's experimentation and wargaming facilities and provide access to authoritative, fielded C2 systems and other applications.

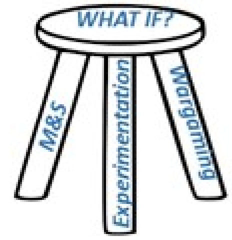


**Figure 3:** *M&S, Experimentation and Wargaming.*

## 5 Conclusions

To adopt a well-worn metaphor, M&S, experimentation, and wargaming comprise the 3 legs of the "What If?" stool that is the critical to ensuring the future success of the U.S. military (Figure 3). Continued DoD investments in each of these methods and their supporting technologies are critical.

As evident (hopefully) from the summaries given in the previous sections, there are not precise delineations among M&S, experimentation and wargaming – M&S may be used to support an experiment or wargame; a wargame might be viewed as an experiment and vice versa; where the presence of a "thinking opposing force" is a key characteristic of a wargame, such an OPFOR may also be present in an experiment; while we may tend to think of wargaming and

experimentation as having human participants in a prominent role, human-in-the-loop M&S applications are also widely used.

Each of M&S, experimentation and wargaming exist on a spectrum ranging from very basic applications to the highly complex. In many ways, these techniques are fundamentally intertwined and there are meaningful opportunities for reuse and cross-domain solutions within this space. We encourage researchers and practitioners in these areas to maintain a wide aperture in their pursuits, and work toward an inclusive community of interest.

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